Development of a High-Efficiency Natural Gas-to-Hydrogen Fueling System

Presented by:

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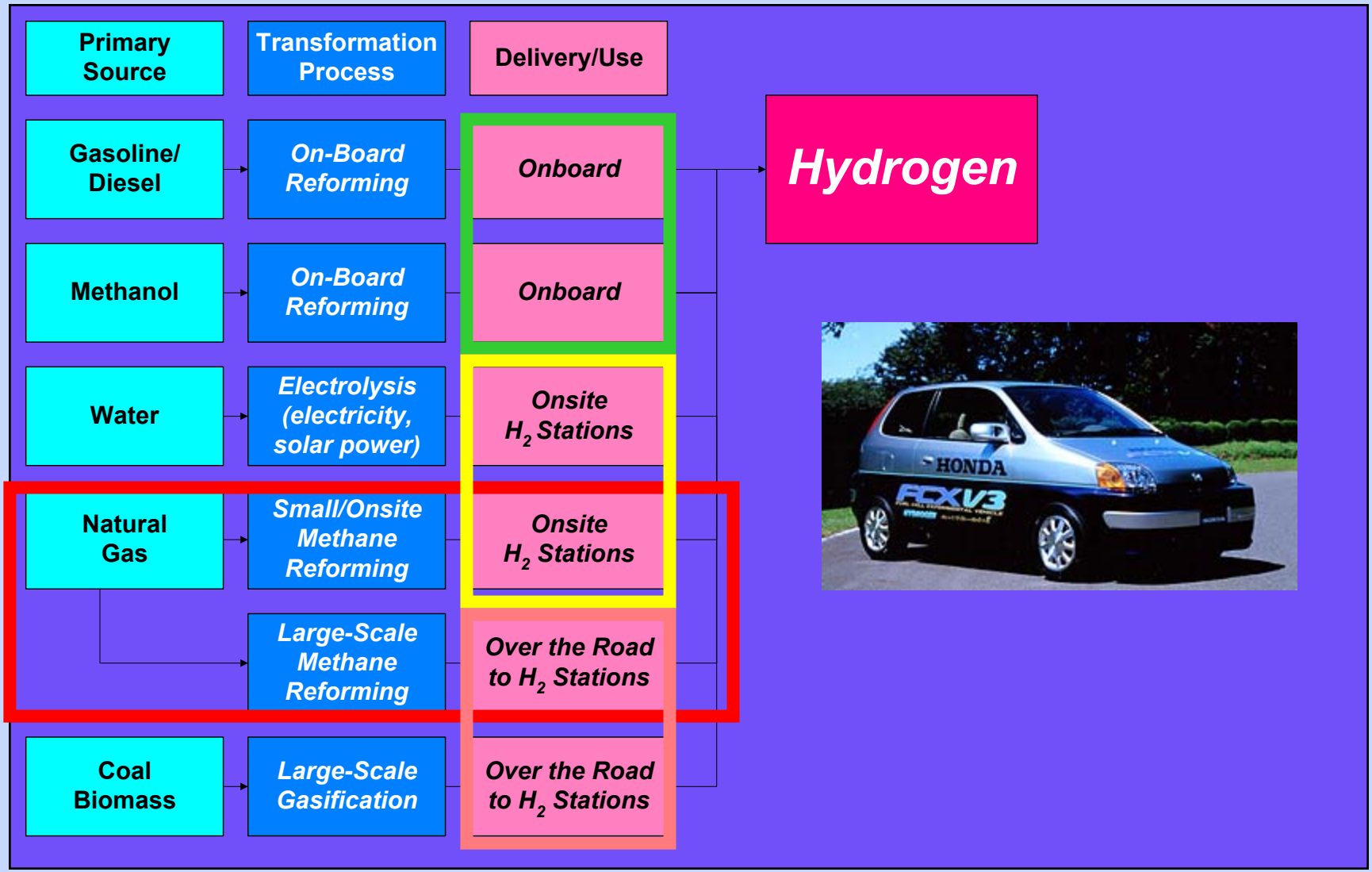
October, 2001

Hydrogen Supply & Infrastructure



DOE/GTI Hydrogen Fueling Program

- **High-Efficiency Onsite Steam Methane Reforming**
  - **$4.2 million program**
    - Partners: FuelMaker Corp., Tulsa Gas Technologies, others
  - **Address:**
    - High-efficiency steam methane reforming
    - Innovative fuel processing
    - Appliance-quality hydrogen compression
    - Advanced fuel dispenser
    - System modeling (performance, economics)
    - System control and integrated product development for reliability and cost
  - **Leverage substantial compressed gas vehicle experience**

gti

Natural Gas Reforming

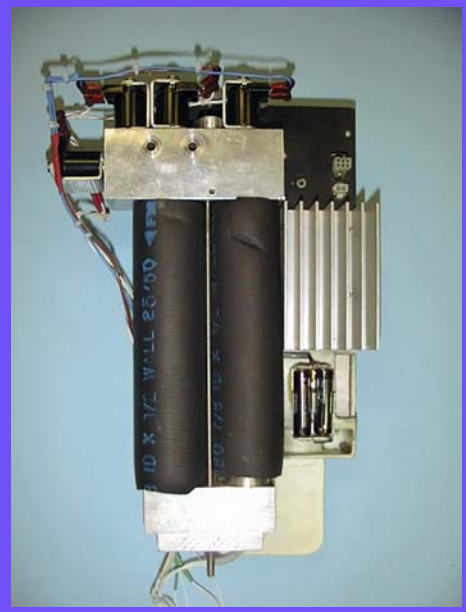
- **Extensive Experience Reforming Natural Gas (and other fuels) to Hydrogen**
  - **40 years of fuel cell experience**
- **Current PEM System for Stationary Market**
  - **Mosaic Energy**
    - Natural Gas
    - Naphtha
- **Modifying Design For H2 Generation**

Mosaic Energy – Early PEM prototype on Natural Gas

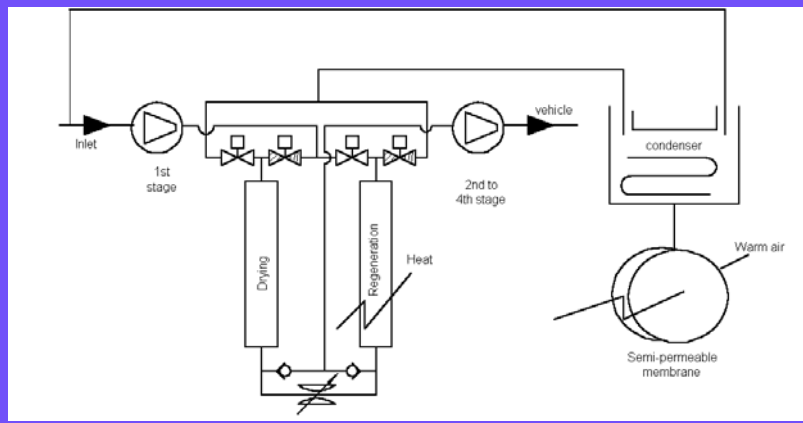
Mosaic Energy PEM fuel cell in Tokyo running on reformed naphtha

Gas Processing

- Develop Compact and Regenerable System
  - Remove water and carbon dioxide (CO2)
- Based on FuelMaker's current Dryer technology
  - Integrated columns, manifold, valves, heaters, and controls
  - Evaluate membranes and dessicants
- Integrate Compression and Dryer/Purifier Systems Into One Appliance



FuelMaker – Compact TSA/PSA Unit



Gas Compression

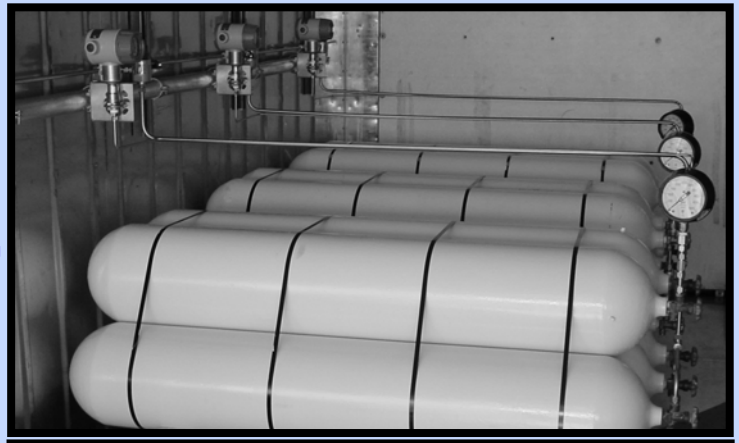
- Compressor Design/Development
  - Modifications for reformate stream, increased operating pressure, and integration of the Dryer/Purifier
- Motor Design and Selection
  - Evaluate AC, DC, variable speed operation
- Controls Design
  - 7500 psig operation, cost/reliability impact
- Electronics and Software
  - Operation of compression, Dryer/Purifier, and dispenser
- Build Benchscale Prototypes
  - Extensive testing and modifications to attain flowrate/power/pressure targets

Concept Based on Current FMQ-10 NGV Product

FuelMaker

Gas Storage & Dispensing

- **GTI Will Develop "Hydrogen AccuFill" System**
  - **Conduct Low, Mid, and High-Temperature Fill Tests In GTI Environmental Chamber**
  - **Use First Principle Thermodynamic Model (CHARGE) To Develop Filling Algorithm**
    - Patented Approach for Accurate Fast-Fill Dispensing
  - **Address Fast-Fill Temperature Rise**

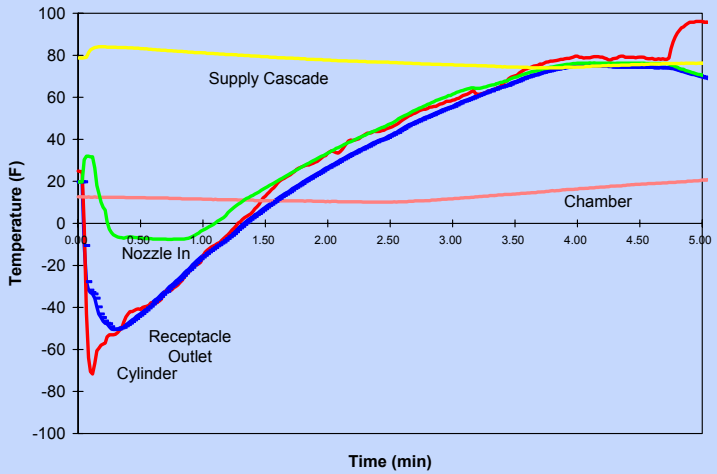


Testing in GTI's 3000 ft³ Environmental Chamber (High and Low Temp.)

Full Size 7000 psig H2 Cascade (11,000 scf)

Evaluate on Three Different H2 Vehicle Cylinders (steel, aluminum, plastic liners)

Precision Instrumentation



Hydrogen Dispensing

- Work With Leading High-Pressure Dispenser Manufacturer
  - Public-Style H2 Dispenser With TGT
  - FuelMaker to produce private fast-fill system
- Modify CNG Dispenser for High-Pressure H2
- Address Range of Issues:
  - Meter availability, display units for public sale, high-pressure hose availability, suitability for Group B service
- Incorporation of AccuFill Algorithm

Tulsa Gas Technologies CNG Dispenser

Sponsored by GTI

System Modeling
Economic and Systems Analysis

- **Hydrogen Fuel Station Economic Model**
  - **Builds on extensive NGV experience**
- **Features:**
  - **Variable & probabilistic costs**
  - **Variable utilization and life**
  - **Tax, incentive, and subsidy effects**
- **Monte Carlo Functionality**
- **Use HYSIS for Process Modeling**

Hydrogen Reformer Fueling Station Economic Model

Operating Parameters

Station Output	kg/day	50.0	427	scf/kg
Compressor Output	scfm	20.0		
Gas Cost	$/Mcf	3.782		
Reformer Flow Ratio (H2 out/NG in)		1.99		
Reformer Burner Flow Fraction		46.9%		
Reformer Gas Consumption	scfh	603		
Reformer Utility Gas Cost	$/hr	1.07		
Reformer Processed Gas Cost	$/hr	1.21		
Electric Cost (nom/L/H)	$/kWh	0.07	0.04	0.15
Electric Demand Cost (nom/L/H)	$/kW/mo.	20	0	40
Total Electric Load	kW	16		

Utilization

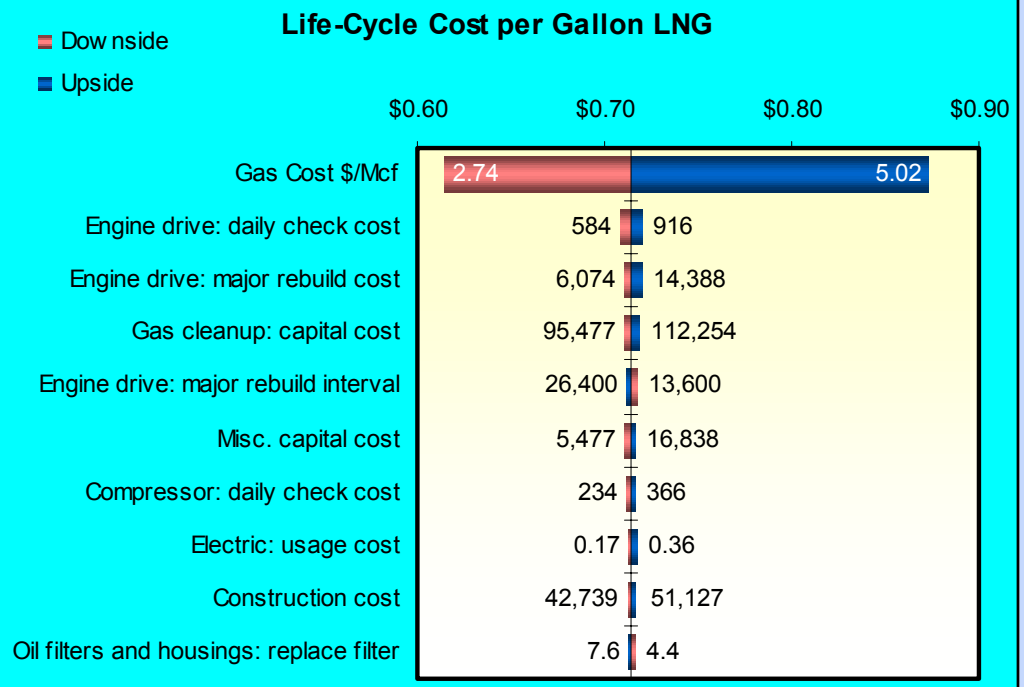
Initial Utilization	0%	100.0%
Growth Rate Factor	2/.01	1
Max. Utilization		100.0%
Years to Max. Utilization	100%	4
Operating Days per Year	6500	365
Operating Hours per Day		18

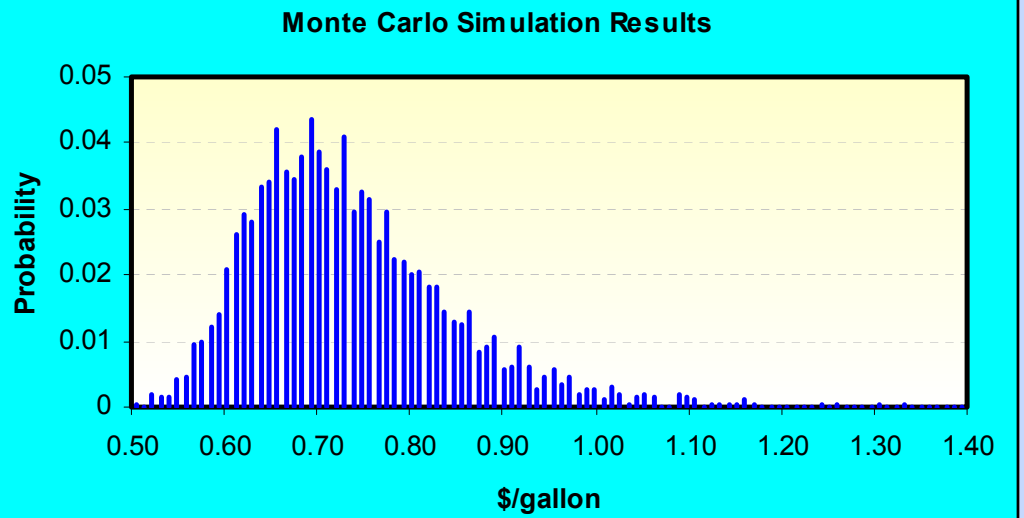
Financial Parameters

Fueling Station Useful Life	yrs	10
Working Capital	% of Δ inc.	2.6%
Salvage Value	of orig.	0%
Depreciation Method		M
Real Discount Rate	annual	8%
Marginal Tax Rate		34%

Economic Analysis

- **Sensitivity Analyses**
  - Identifies major station cost elements that influence life-cycle costs
- **Monte Carlo Simulations**
  - Yield a distribution of expected life-cycle costs
  - Range of probable to possible costs



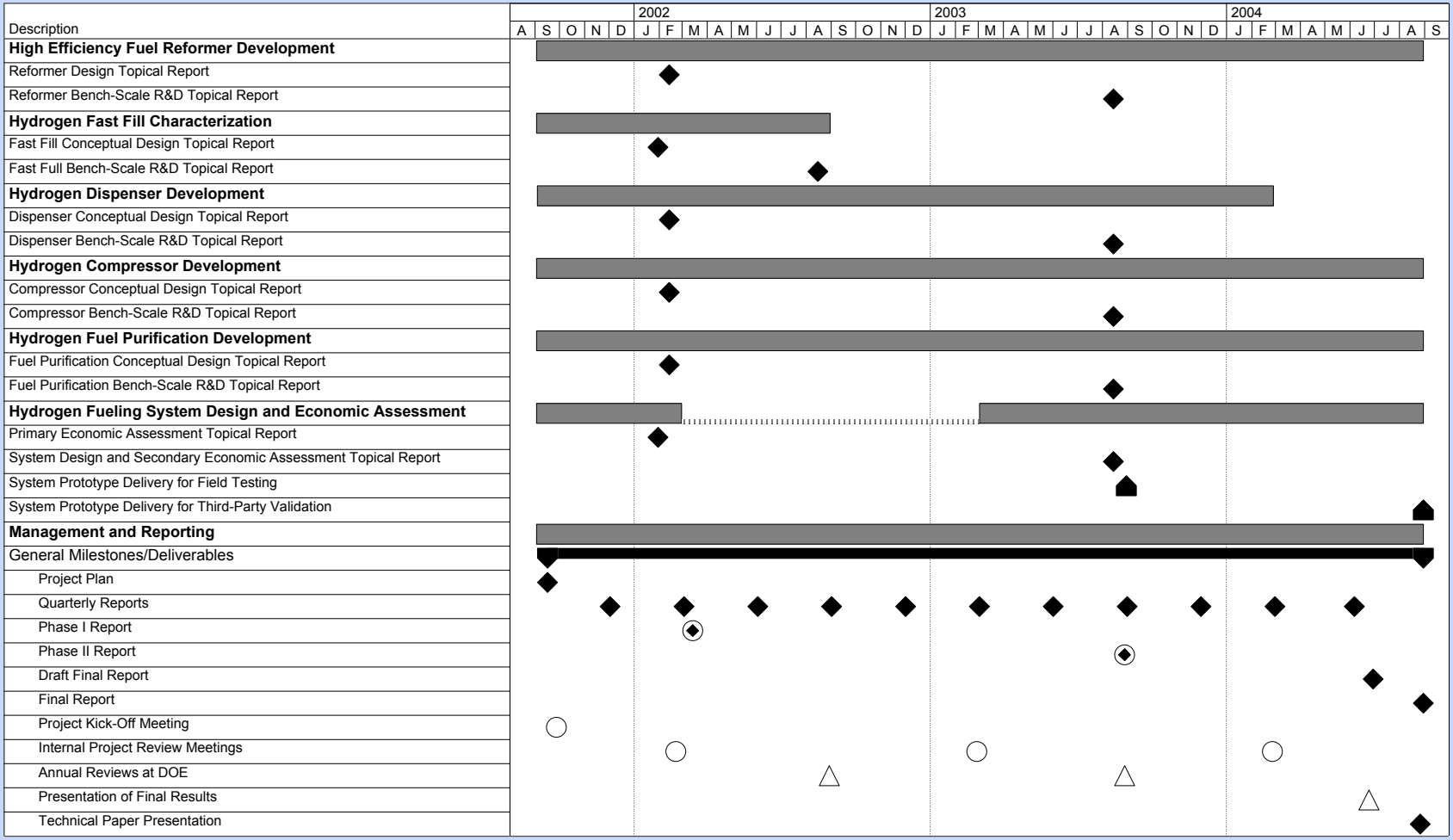


Example – Small-Scale Natural Gas Liquefier

Targeted Benefits: Systems & Subsystems

SYSTEM INTEGRATION →					
REFORMERS	**PURIFIERS**	**COMPRESSORS**	**DISPENSERS**	**STORAGE**	Comprehensive Hydrogen Fueling Station design (GTI and FuelMaker).
Natural gas reformers suitable for H2 fueling stations and stationary fuel cells (from GTI/Mosaic Energy). Liquid fuel-based reformers for hydrogen fueling stations and stationary fuel cells (from GTI/Mosaic Energy and IHI).	Cost effective strategies for natural gas cleanup, shift conversion, and CO removal (from GTI/ Mosaic Energy). Highly innovative product strategies for post-reformer water and CO2 removal (from FuelMaker).	Family of appliance-quality products for H_2 fueling (FuelMaker). Units ranging from individual home fueling systems to integrated designs for larger stations. Suitable for use with time fill or fast fill vehicle applications. Compressors suited for use with reformer or electrolyzer-based equipment (FuelMaker and Stuart Energy).	High-quality Hydrogen Dispenser for public fueling (from Tulsa Gas Technologies). Integrated dispensing strategies (with compressor appliance) for low-cost onsite H2 fueling (from FuelMaker). State-of-the-Art fast fill algorithm for addressing hydrogen underfill issues (GTI and FuelMaker).	Demonstrated hydrogen cascade storage system for hydrogen fueling stations (Norris Cylinder Company).	Strategies for integration of reformer, purifier, and compressor operation (GTI and FuelMaker). Computer program - CASCADE - for sizing H_2 compressors and cascade storage systems (GTI). Technology transfer to interested partners in the NGV Fueling Station business (GTI/Blue Energy).

Program Tasks & Schedule



Summary

- Hydrogen and Natural Gas…Strong Connectivity
- Program Will Build On Substantial NGV Experience
  - Work with leading suppliers to this industry
- Project Slightly Behind Schedule
  - Contracting issues
- Expect Range of Products To Result From This Program
  - Hydrogen compressors, dispensers, filling algorithms, fuel clean-up strategies…

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